Shear Estimation

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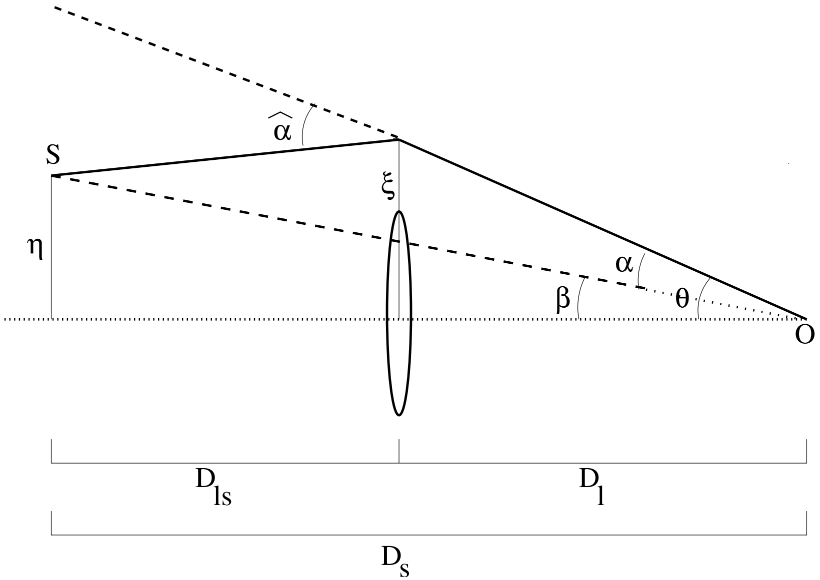
November 18, 2013

%sectionIntroduction

Abell 370, HST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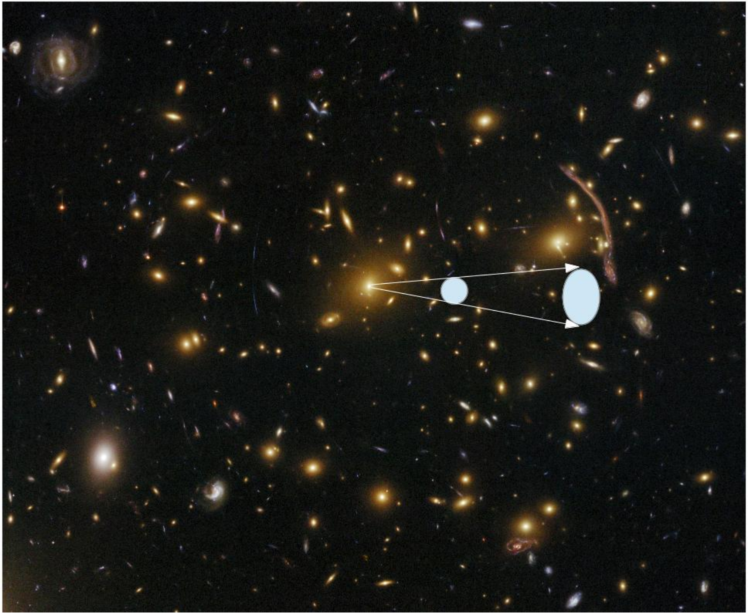
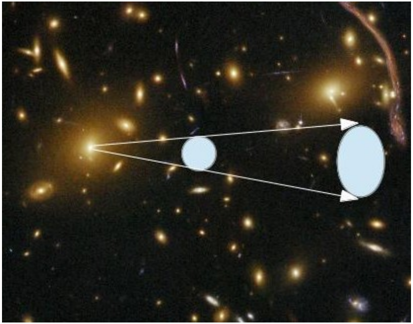
Shear Illustration

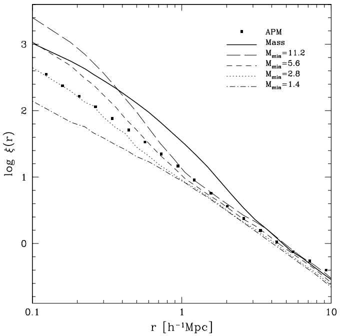


- The path of light appears curved as it passes massive objects
- The "deflection" can differ across the face of an extended source galaxy, causing distortion.
- Shear distorts the image; we say it's "shape" is altered.
- For small shears, a circle becomes a pure ellipse.
- Shearing produces correlations in the shapes of galaxies across the sky. Shape correlations are closely related to mass density correlations.



Note galaxies aren't round!
"Shape noise"

- The correlations in the shear/matter field hold a lot of information about the **Dark Matter** distribution. The Cold Dark Matter theory predicts these correlations.
- Shear depends on the distances to the lens and source. The distance dependence encodes the expansion rate of the universe and thus **Dark Energy**.
- To meet goals of current surveys we want to measure shear to about 0.3-0.4% accuracy (e.g. Dark Energy Survey). LSST about a factor of five better.



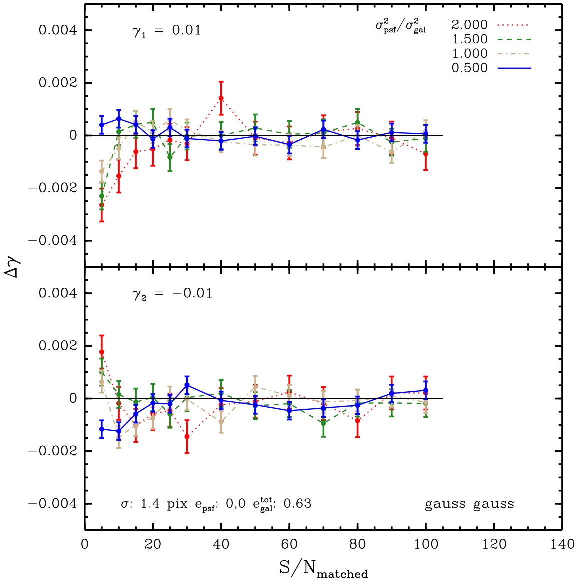
Berlind & Weinberg 2002

- For a perfect detector with no noise, just measure the second moments and look for the correlations.
- ... but the atmosphere, telescope, and instrument smear the image: the Point Spread Function (PSF).
- Convolution just adds to the moments, so we just need to subtract off the PSF moments!
- ... but there is noise, so error in moments blows up (among other difficulties).

- One can use a weight function to suppress the noise, but then one must derive how that measurement responds to smearing by the PSF and shearing (e.g. Kaiser, Squires, & Broadhurst, Bernstein & Jarvis, Melchior, Bernstein & Armstrong). Working in Fourier space can help with the deconvolution (Bernstein).
- Alternatively, one can forward-model the problem: fit a model that is convolved with an estimate of the PSF. Limited by how well one can model the galaxy and PSF (e.g. Miller et al., Bernstein & Armstrong, many others).
- These methods can be made to work well, as long as the S/N is still pretty high, say 50 or higher.

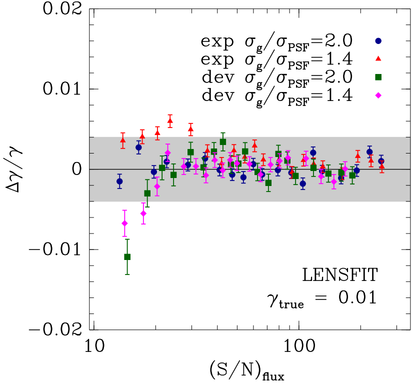
Noise

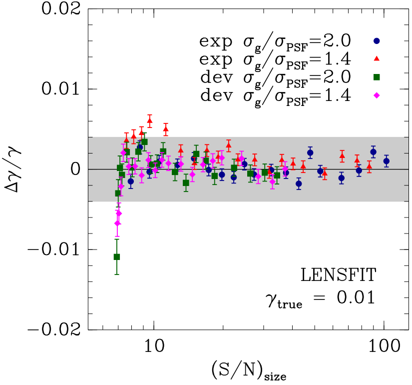
- When the S/N is low, these techniques break down.
- Non-linear fitting in the presence of noise is biased, both the maximum likelihood and expectation value: using the mean shape won't work (Hirata, Refregier, etc). Results in a **calibration** error.
- This is generally known in statistics, but not yet solved for our particular problem. Badly aggravated by the PSF "deconvolution".
- The noise also causes problems for moment based methods.



$\gamma_1 = 0.01$
$\sigma^2_{psf}/\sigma^2_{gal}$
2.000
1.500
1.000
0.500
0.004
0.002
0
−0.002
−0.004
$\Delta\gamma$
$\gamma_2 = -0.01$
σ: 1.4 pix e_{psf}: 0,0 e^{tot}_{gal}: 0.63
gauss gauss
0
20
40
60
80
100
120
140
$S/N_{matched}$

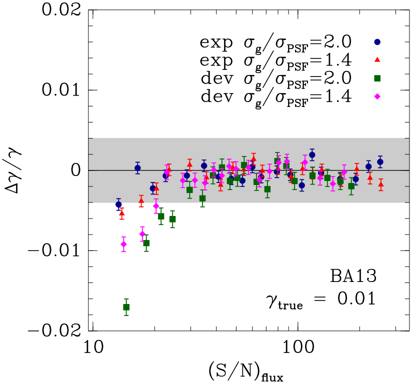
- Miller et al. 2007 (LENSFIT): Use priors on the parameters and explore a constrained posterior surface (Prior $\times$ Likelihood).
- Attempt to derive how the shear estimate (the shape) affected by the noise and prior using integrals over the posterior surface and first order approximation in shear. Called the **response**.
- The posterior surface of the shape for a single galaxy is complex. The space is bounded, the surface is necessarily asymmetric and depends on galaxy properties and noise.
- No rigorous expression is given for the mean shear of a population given these ellipticity responses. Choose to simply average them.
- Miller et al. 2013 find large biases in simulations, of order 10% at $(S/N)_{\mathrm{flux}} \sim 10$.

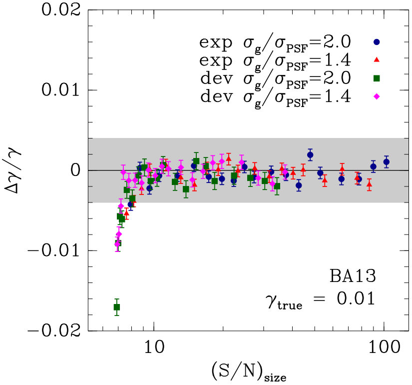




- I did my own tests of LENSFIT with strong structural priors (30% lognormal on flux, 15% on size (that was a bug...)).
- Very fast code using gaussian mixtures to approximate galaxies. Fast analytic convolutions.
- Bias vs $(S/N)_{\rm size}$ has more universal form than vs $(S/N)_{\rm flux}$.

- Shape is not shear.
- While the posterior surface for the *shape* of single galaxy is complex, the posterior surface for the *mean shear* of an ensemble must approach a Gaussian according to the central limit theorem. This is both useful and actually true!
- Assuming Gaussianity, weak shear, and knowledge of underlying distribution of shapes for the ensemble (the prior), one can derive an unbiased estimator for the mean shear of the ensemble.
- You lose nothing: in the limit of weak shear, you need to use an ensemble statistic anyway. The "shape noise", intrinsic variance in shapes of galaxies, dominates over the signal.
- This is a good idea, but needed an implementation, so I worked it into my existing code.





- Assuming we can find the right model.
- Sufficient accuracy for DES at $(S/N)_{\mathrm{size}} > 10$.

- Can push to lower $(S/N)_{\mathrm{size}}$ than LENSFIT.
- Bias varies with $(S/N)_{\mathrm{size}}$ in a simpler way than LENSFIT.
- Bias vs $(S/N)_{\mathrm{size}}$ even more universal. Sufficient accuracy for DES at $(S/N)_{\mathrm{size}} > 10$.

- I'm assuming I can find the right model. Not true in real data. Should be OK for DES (Kacprzak et al. 2013) but not LSST.
- TODO:
  - Explore more realistic intrinsic distributions in structural parameters (size, flux). E.g. for a bin in *measured* flux, what are the *true* distributions in size and flux? Use Cosmos.
  - Why is there bias at all? Is it the likelhood sampling method?
  - Bernstein & Armstrong propose a model-independent technique using moments in Fourier space, but not yet implemented. Gary and Bob plan to do it. Student at Stony Brooke as well (Madhavacheril).

Summary

- Shear estimation is difficult in the presence of noise.
- Modern techniques can work well enough for current surveys.
- For future experiments such as LSST we need a model-independent approach.